AN OCEANOGRAPHIC INVESTIGATION OF MESOSTRUCTURE NEAR ARCTIC ICE MARGINS

William Russell Corse

NAVAL POSTGRADUATE SCHOOL

Monterey, California

THESIS

AN OCEANOGRAPHIC INVESTIGATION

OF

MESOSTRUCTURE NEAR ARCTIC ICE MARGINS

by

William Russell Corse

September 1974

Thesis Advisor: R. G. Paquette

Approved for public release; distribution unlimited.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) AN OCEANOGRAPHIC INVESTIGATION OF MESOSTRUCTURE NEAR ARCTIC ICE MARGINS		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis; September 1974
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) William Russell Corse		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		12. REPORT DATE September 1974
		13. NUMBER OF PAGES 54
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) Naval Postgraduate School Monterey, California 93940		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Mesostructure; Microstructure; Arctic; Underwater Sound; Oceanography; Chukchi Sea; Ice; MIZPAC; Internal Waves

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The origin and continuity of complex temperature profiles observed in the Chukchi Sea as part of the MIZPAC 71 program was investigated. The positive temperature anomalies, termed mesostructure elements, were found to have their heat source in the warm coastal current. Interleaving coupled with mixing in the marginal ice zone due to ice protuberances was found to account for the temperature features observed.

DD FORM 1 JAN 73 1473 (Page 1) EDITION OF 1 NOV 65 IS OBSOLETE S/N 0102-014-6601 |

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Block 20 - ABSTRACT (Cont.)

Particular mesostructure elements were traced for several km. The deeper structure was found to occur in some association with a rhythmic deepening of constant density surfaces, possibly due to tidal influence.

An Oceanographic Investigation

of

Mesostructure Near Arctic Ice Margins

by

William Russell Corse
Ensign, United States Navy
B.S., United States Naval Academy, 1973

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OCEANOGRAPHY

from the

NAVAL POSTGRADUATE SCHOOL
September 1974

ABSTRACT

The origin and continuity of complex temperature profiles observed in the Chukchi Sea as part of the MIZPAC 71 program was investigated. The positive temperature anomalies, termed mesostructure elements, were found to have their heat source in the warm coastal current. Interleaving coupled with mixing in the marginal ice zone due to ice protuberances was found to account for the temperature features observed. Particular mesostructure elements were traced for several km. The deeper structure was found to occur in some association with a rhythmic deepening of constant density surfaces, possibly due to tidal influence.

TABLE OF CONTENTS

I. INTRODUCTION -- 9

A. ORIGIN OF STUDY ---------------------------------- 9

B. OCEANOGRAPHY OF THE MIZPAC 71 AREA ----------- 10

C. MARGINAL ICE ZONE CHARACTERISTICS ------------ 11

D. MESOSTRUCTURE DEFINITION --------------------- 14

E. MESOSTRUCTURE DISTRIBUTION ------------------- 18

II. METHOD OF ATTACK -------------------------------- 20

A. SUMMARY OF ANALYSES PERFORMED ---------------- 20

III. DATA-INDUCED LIMITATIONS ------------------------ 21

IV. DISCUSSION --------------------------------------- 22

A. ESTIMATES OF LENGTH AND TIME SCALES OF MESOSTRUCTURE ELEMENTS ----------------------- 22

B. CHARACTERISTICS OF STATIONS 131-163 ---------- 34

C. COMPARISON OF STATIONS IN THE ICE MARGIN WITH AND WITHOUT MESOSTRUCTURE -------------------- 40

D. ORIGIN OF MESOSTRUCTURE ELEMENTS ------------- 41

BIBLIOGRAPHY -- 51

INITIAL DISTRIBUTION LIST ------------------------------ 53

LIST OF FIGURES

Figure

1. MIZPAC 71 station positions ---------------------- 12
2. Plan view of maximum temperature in the water column. Temperature in °C ----------------------- 13
3. Ice concentrations in oktas (eights) from observations on station, 1971 ------------------ 15
4. Definition of mesostructure elements and nose feature -- 16
5. Distribution of mesostructure in the MIZPAC 71 area -- 19
6. Characteristics of mesostructure elements in stations 131-133 -------------------------------- 24
7. Characteristics of mesostructure elements in stations 144-145 -------------------------------- 25
8. Characteristics of mesostructure elements in stations 146-148 -------------------------------- 26
9. T-Z profiles of stations 7-16 nested with one-degree separations ------------------------------ 28
10. T-Z profiles of stations 17-30 nested with one-degree separations ------------------------------ 29
11. T-Z profiles of stations 30-35 nested with one-degree separations ------------------------------ 30
12. Depth/Density characteristics of stations 7-35 -- 32
13. Depth/Density characteristics of stations 131-141 (18 August) ------------------------------------ 35

Figure

14. Depth/Density characteristics of stations 142-159 (19 August) -- 36

15. Depth/Density characteristics of stations 160-163 (20 August) -- 37

16. Estimated times of occurrence of density minimums and maximums for MIZPAC 71 stations 7-35 and 131-159 -- 39

17. Maximum temperatures for some MIZPAC 71 stations inside the ice margin ----------------------------- 42

18. Typical characteristics of MIZPAC 71 stations south of the ice margin in the coastal current -- 45

19. Mesostructure formation and decay within the marginal ice zone -------------------------------- 46

20. T-S grouping of stations 17,18,19,20 ------------ 49

21. T-S grouping of stations 33,34,35 --------------- 50

ACKNOWLEDGEMENT

The author wishes to express his gratitude to Dr. R. G. Paquette of the Naval Postgraduate School faculty for his patience and astute suggestions during the course of this effort, and for the use of several computer programs. Dr. Robert Haney provided helpful comments concerning turbulence theories. Finally, Donna Sadel helped with some of the figures and typing, and kept the light on inside the author.

I. INTRODUCTION

A. ORIGIN OF STUDY

The present work was undertaken to find the mechanisms by which mesostructure forms in temperature profiles in and near Arctic ice margins. The term "mesostructure" merely implies larger temperature fluctuations than those found elsewhere and termed "microstructure". The body of data examined was gathered in July and August 1971 by Paquette (Paquette and Bourke, 1973). It consists of about 150 lowerings of a salinity-temperature depth recorder (STD) supplemented by discrete random samples made with a hand-lowered instrument. That part of the data used came from the northeastern Chukchi Sea not far from the Alaskan coast, collected as part of the MIZPAC 71 (Marginal Ice Zone, Pacific) program.

Length and time scales of mesostructure and mechanisms for its formation were examined using both hand-plotted and computer-generated graphic techniques of data display. It was found that warm near-surface water was mixed down into the water column and advected across the Chukchi shelf at a relatively high rate of speed to form interleaving features. Large changes in mesostructure characteristics in the space of 1km suggest that mesostructure may form over short distances and that the process may have highly preferred orientations.

The discussion of mesostructure in the present work will be introduced by a brief oceanographic description of the area studied. Following this, an outline of the method of attack with a summary of the analyses performed and data-induced limitations will be presented. Then, an examination of the data will be performed which consists of both a temporal and spatial analysis of individual mesostructure elements and mesostructure in general. Finally the origin of mesostructure will be discussed.

B. OCEANOGRAPHY OF THE MIZPAC 71 AREA

The Chukchi Sea is a shallow marginal sea. All but its eastern edge is 30 fathoms deep or less. Near the eastern border is the Barrow Sea Valley, extending from 15 miles north of Point Franklin in a northeasterly direction. Near its northern boundary the Chukchi Sea deepens and the bottom eventually descends into the Arctic Ocean basin.

The coastal circulation of the eastern Chukchi Sea is dominated by a warm current, presently having no accepted name. It will be referred to as the "coastal current." The current has its origin in the Bering Strait. At Cape Lisburne it apparently splits, with some flow turning to the northeastward. The right-hand branch is generally closely compressed against the Alaskan Coast. Paquette and Bourke (1973) found that at least part of the current turned sharply to the right into the Beaufort Sea at a point about 55km past Pt. Barrow. They found that beyond this point part of the current, with diminished heat and kinetic energy, ran more or

less parallel to the shore to 152°W. Current speeds are somewhat uncertain, but speeds in the core are probably on the order of 1 knot or more in the south and sometimes over 2 knots west of Pt. Barrow.

The temperature maximum of the current varies from year to year. In the period June through September maximum temperatures of 5-11°C have been found. MIZPAC 72 observed warm water up to 10°C at 167°W in the Chukchi Sea. However, maximum temperatures in the MIZPAC 71 operating area (see Figure 1) were approximately 6°C. Figure 2 shows the horizontal distributions of the maximum temperature in the water column during MIZPAC 71.

Maximum temperatures are at the surface towards the coast, but at lower levels further to seaward in both the Chukchi and Beaufort Seas. Also, the depth of maximum temperature increases rapidly near the Barrow Sea Valley. This is apparently because the water is finding a deeper equilibrium level. Paquette and Bourke (1973) suggested that the Barrow Sea Valley may act as a drain for the dense underlying water. When this happens the warm water merely descends to fill the column.

C. MARGINAL ICE ZONE CHARACTERISTICS

The ice margin of the Chukchi Sea changes markedly between about 1 July and 15 September. In this period ice melts back from the Bering Strait to approximately 73°N. Factors which influence the exact position are the heat and kinetic energy of the coastal current, local river discharge,

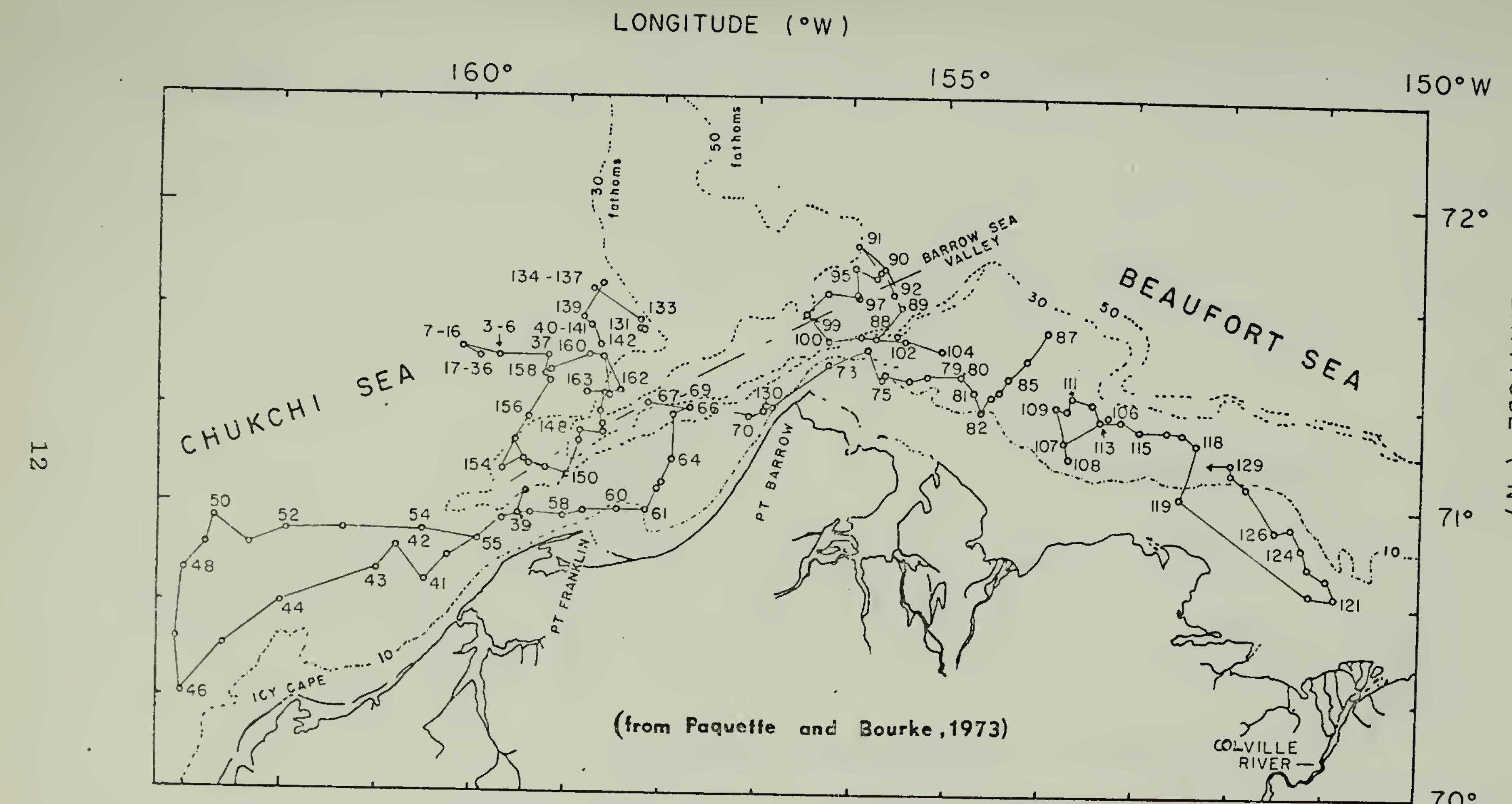


Figure 1. MIZPAC 71 station positions.

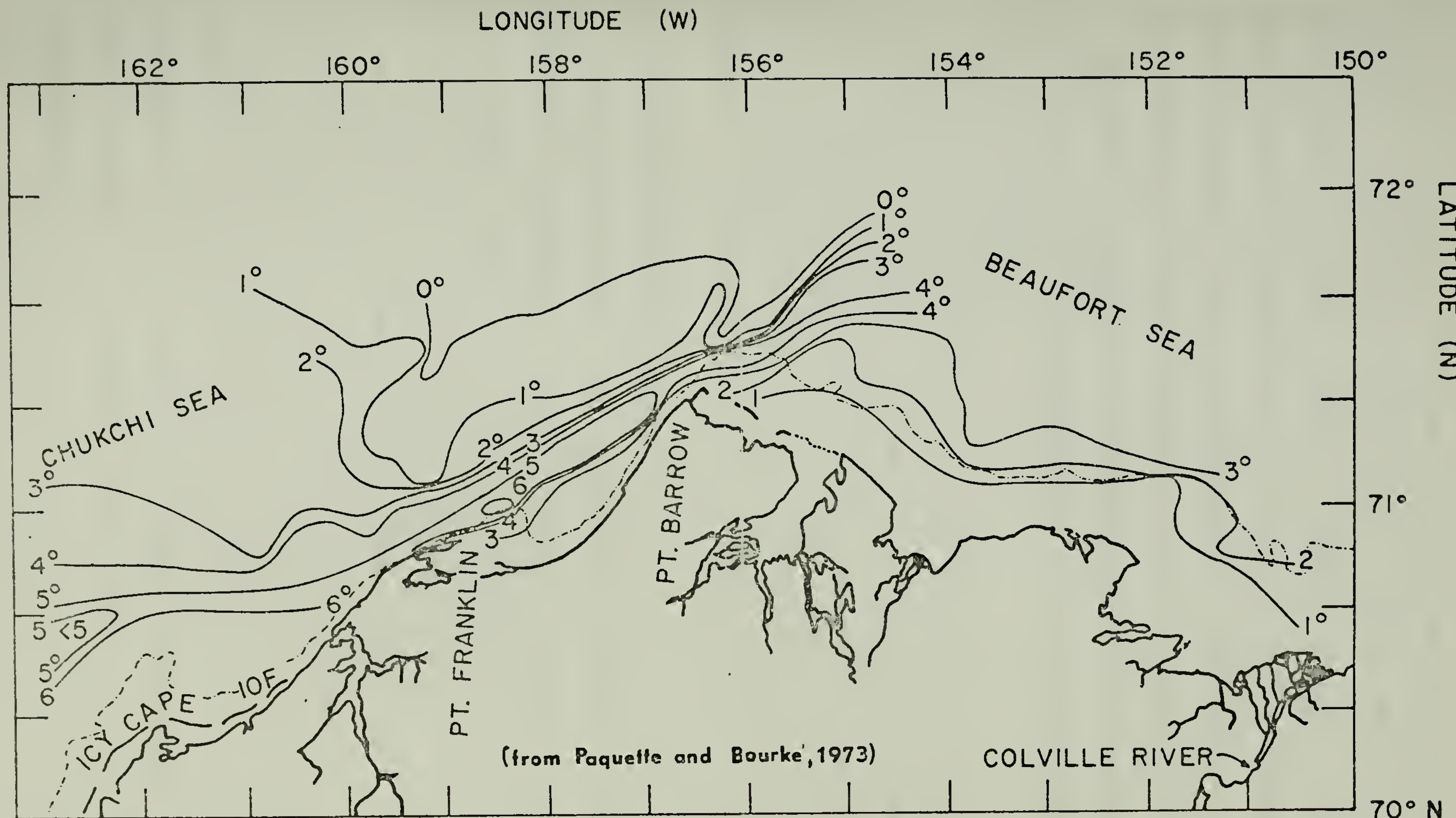


Figure 2. Plan view of maximum temperature in the water column. Temperature in °C.

and wind direction. If winds in the area are from the west or north, a diffuse ice margin will result, whereas winds from the east or south produce a compact margin. During MIZPAC 71 the ice margin was diffuse, scattered south to Icy Cape. The year 1971 was considered a "normal" year for melting. Daily and weekly changes of the ice margin were large, but the exact nature of the changes could not be determined, since little aerial reconnaissance could be done and fog restricted visibility.

Figure 3 presents the ice distribution in oktas during the MIZPAC 71 cruise. The numbered dots are station positions. Rather than being synoptic, this chart shows concentrations estimated while the stations in an area were being occupied. The influence of the coastal current is evident.

D. MESOSTRUCTURE DEFINITION

The term mesostructure can best be described using some examples from MIZPAC 71 data. Figure 4 shows the temperature versus depth profiles for a typical station and the corresponding density versus depth profiles for the station.

As Figure 4 shows, mesostructure elements are divided into three classes. They consist of a nose feature with vertical extent of about 5m. and $\sigma_t < 25.0$, shallow mesostructure with $\sigma_t < 25.5$, and deep mesostructure in the density range $25.5 \leq \sigma_t \leq 26.3$. Much of the shallow mesostructure in Figure 4 underlies a shallow nose, as will be seen in subsequent figures.

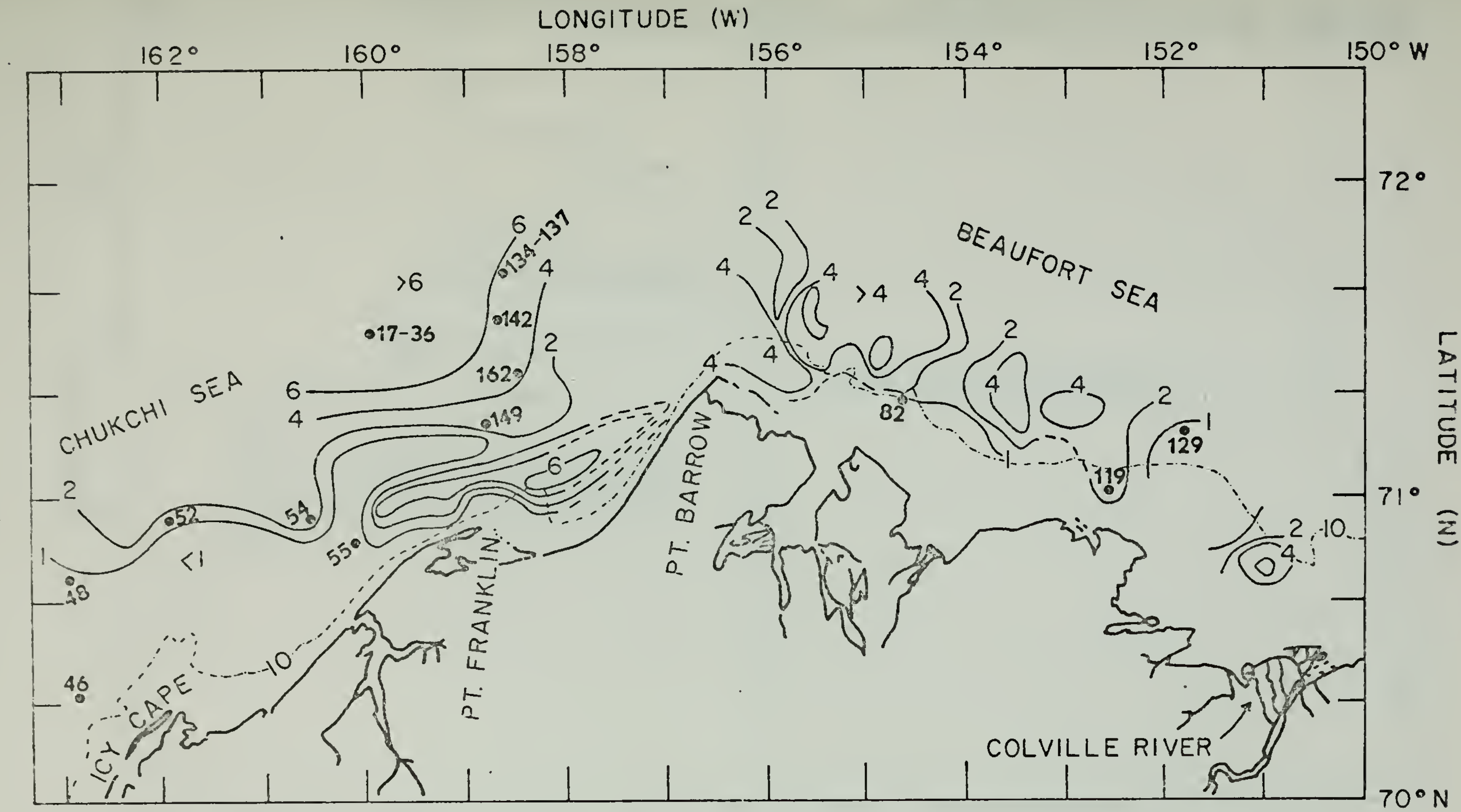


Figure 3. Ice concentrations in oktas (eights) from observations on station, 1971.

Numbered dots indicate station positions.

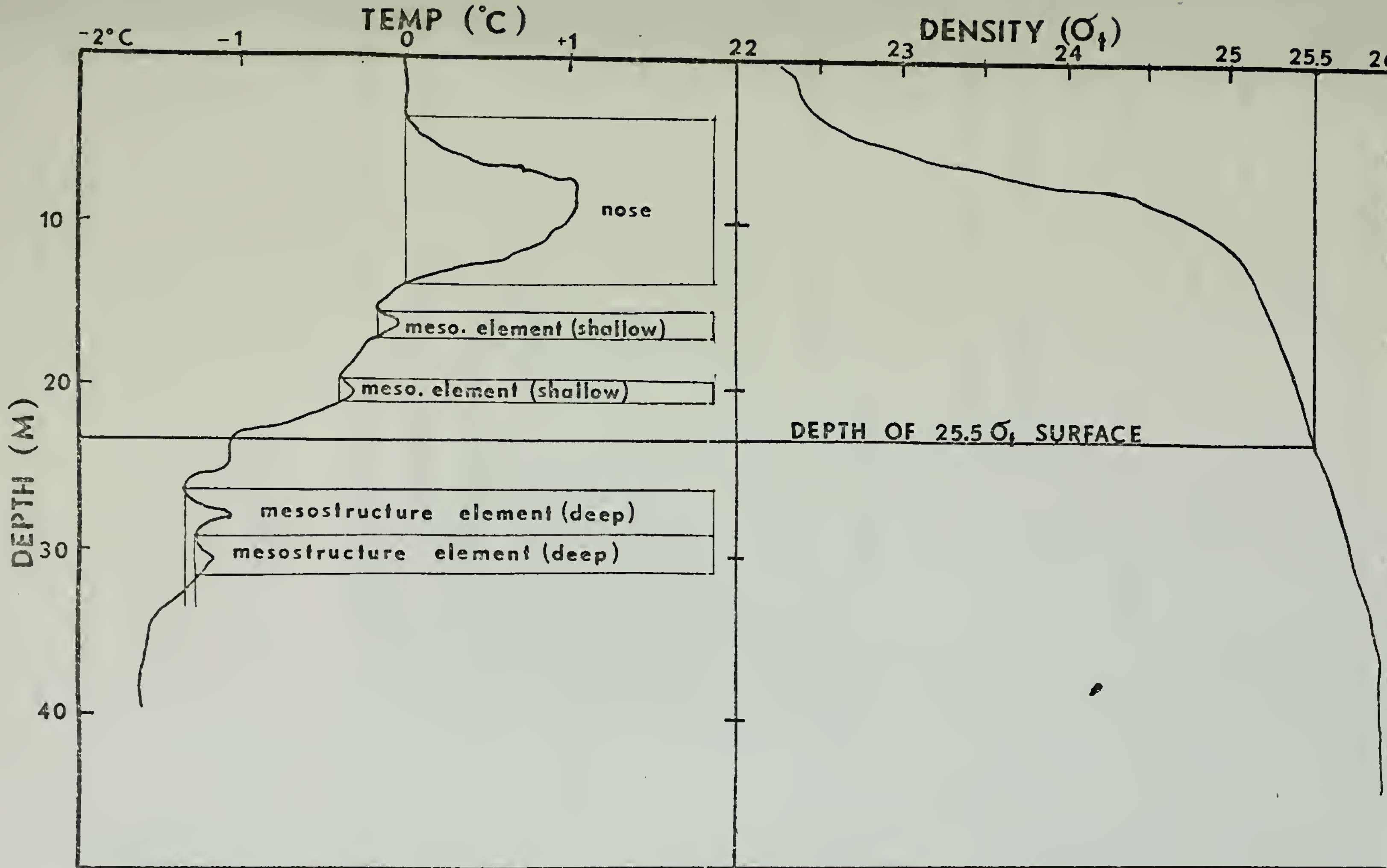


Figure 4. Definition of mesostructure elements and nose feature.

For the purpose of this work a mesostructure element is defined to extend from the depth where the temperature gradient becomes positive to the depth at which the temperature is the same value as it had when the gradient became positive. If, after the temperature gradient becomes negative, it again goes positive before that temperature is reached, that point is taken as the end of one mesostructure element and the beginning of another. In addition, any region of warmer water extending over more than five meters in depth is called a nose.

The choice of the mesostructure definition in the present discussion was somewhat arbitrary, but warm anomalies in the profile were chosen rather than cold ones since the advection of warm water was found to be associated with mesostructure. Other definitions are possible.

Garrison et al. (1974) have defined mesostructure elements to consist of what might be described as a "half layer." This half layer was defined to extend from the depth where it became negative, or vice-versa. They made no depth or size restrictions, but temperature differences less than .03°C were ignored.

It does not appear that mesostructure in the marginal ice zone (MIZ) is of the same origin as microstructure anomalies in the Arctic Ocean measured by Neal and Neshyba (1972), Denner (1971) at Ice Station T-3, or by Denner at Arlis V in 1970. These measurements were of a staircase-like temperature structure with numerous sheets (over 60), and

temperature steps on the order of 0.01°C per step. In the present study most of the structure was not of staircase form and had peak temperature anomalies about 100 times larger than in the studies cited. A little staircase structure could be seen in some of the STD records, but this study has been confined to the more important irregular anomalies previously described.

As will be seen in subsequent figures, the mesostructure elements have little uniformity in vertical extent, temperature change with time, depth, or shape. The vertical scale of the mesostructure elements is within the size found by Denner (1969, 1970). Because of lack of agreement on all other points, however, it is contended that the mesostructure origin is not that of the microstructure discussed above.

Gregg and Cox (1972) in measurements off San Diego found temperature and salinity depth fluctuations in the millimeter range, of the same general shape of mesostructure, superimposed on a staircase structure. However, the difference in scale of the data in this study is so great that this work has, for the present, been considered not applicable to their smaller scale.

E. MESOSTRUCTURE DISTRIBUTION

Figure 5 shows the distribution of the mesostructure in the MIZPAC 71 area. The symbol which indicates shallow and deep mesostructure does not specifically indicate a nose, although a nose is usually present in these instances. Unfortunately, part of the time the Bissett-Berman Model 9006

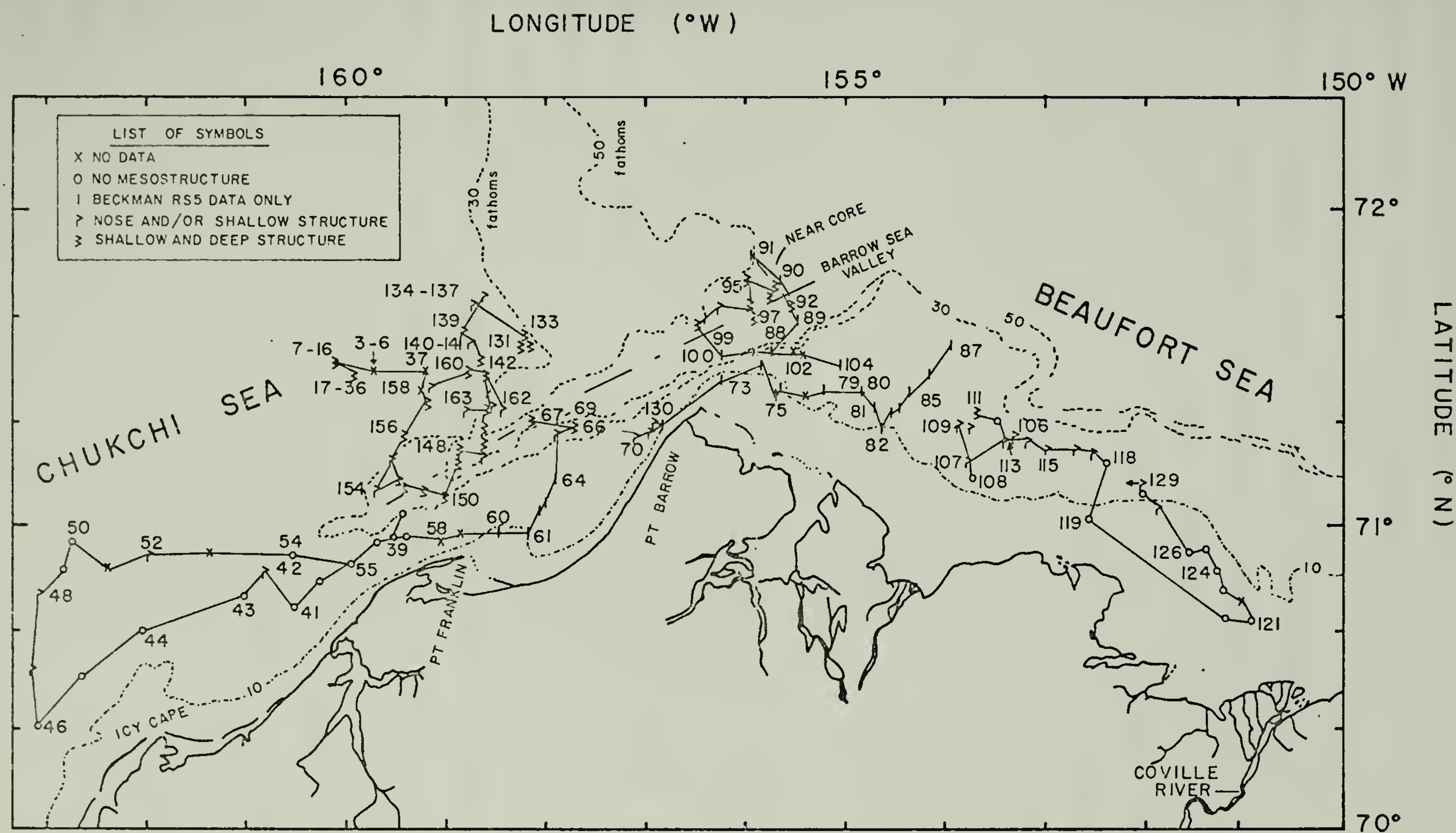


Figure 5. Distribution of mesostructure in the MIZPAC 71 area.

STD was not operational and some stations were taken using the Beckman RS5 conductivity-temperature meter. Since the RS5 provides only discrete readings and a resultant profile resolution far less than the Bissett-Berman 9006 STD, it was decided to concentrate the efforts in mesostructure determination mainly to the area over and just west of the Barrow Sea Valley. Most of the stations in that area were made using the Bissett-Berman STD. In addition, the station concentration over a large area was the highest there. Time series for stations 7-16 and 17-35 were taken in the areas indicated.

II. METHOD OF ATTACK

A. SUMMARY OF ANALYSES PERFORMED

To reiterate, the problem at hand was to determine more about the nature of the mesostructure elements and the reason why only some areas under the ice margin contain mesostructure.

Since very little is known about the mesostructure, it was decided to first determine to what extent, if any, elements can be traced using either several stations in the time series for stations 7-16 and 17-35, (see Fig. 1) or stations both geographically and temporally close. After discussion of these results, the characteristics of mesostructure elements in general are discussed. Depth, temperature, and density distributions of elements are displayed, and any associations of mesostructure with these variables are noted.

Using those characteristics unique to stations with mesostructure (other than the mesostructure itself), a source is determined. Once the nature of the source is known and fully described, general oceanographic features of the MIZPAC 71 area discussed previously are considered in an attempt to determine reasons for the geographical distribution of mesostructure.

Finally, an attempt is made to determine mechanisms for the formation of temperature anomalies (in the water column) of the observed magnitude. Several theories concerning interleaving, generation of instability by breaking internal waves, billow turbulence, and double diffusion are examined to determine the most likely explanation.

III. DATA-INDUCED LIMITATIONS

Because of several commitments of the USCGC Northwind, stations were occupied when time permitted, introducing certain non-idealities. The station arrangement in time and space was not well-suited to tracing phenomena through small increments of lateral distance. In certain interesting cases, not enough information was available to determine whether the phenomena were of local origin or arose in the environs.

However, a time series of 29 stations did occur over a period of 45 hours while the ship was drifting relatively slowly, providing a quasi-continuous look at temporal changes within the water column. Also some station groups were

closely spaced (i.e. 131-133, 146-148), enabling an examination of spatial changes of mesostructure to be made.

IV. DISCUSSION

A. ESTIMATES OF LENGTH AND TIME SCALES OF MESOSTRUCTURE ELEMENTS

In order to determine more about the origin of mesostructure elements and scales of length and duration, several different approaches were taken. The temperature and salinity of mesostructure elements at geographically close stations were compared. Tracing of a particular temperature-depth profile shape from one station to another was tried. Finally, the time series 7-16 and 17-35 were studied to determine if particular structures could be observed at one place over a period of time.

Garrison et al., (1974), using 1972 MIZPAC data, reported that little success was obtained in their attempts to determine the size and shape of individual layers, using their definition of a mesostructure element. Attempts to determine length scales of particular mesostructure elements were only partly successful. Much of the data in the series 131 to 163 gave little indication of a progression of change which could be used to infer some mechanism for the production of mesostructure elements. This is somewhat surprising since some stations were close together in time and space.

Three examples from the data are presented and examined here. Station groups 131-133, 144-145, and 146-148 were

chosen since these station groups were close together and correlation between mesostructure elements was better here than between most stations. Figures 6, 7, and 8 show the temperature versus depth profiles for the three station groups. The inserts of temperature and density were measured at the depths of temperature peaks of the mesostructure elements. The temperature profiles are nested and offset 1°C. The dotted lines in the inserts represent independent attempts to trace mesostructure elements using temperature, and density and shape. It should be noted that the dotted lines tracing temperatures between stations do not always agree with the lines using density and profile shape to follow particular elements. It appears that temperature is a poor way to trace particular structures initially, and is best used to show direction of flow between stations once the mesostructure elements have been traced.

Stations 131-133 (Fig. 6) showed the best correlation, both in general temperature, profile shape, and density of mesostructure elements between stations. The density of the different elements was fairly constant between all three stations. In stations 131-133, station 133 appears to be in the downstream direction, since temperatures are coolest, and the mesostructure elements have smaller positive temperature anomalies. Station 133 is about 2.0km north of station 131, giving an indication of the length scale over which similar elements can exist.

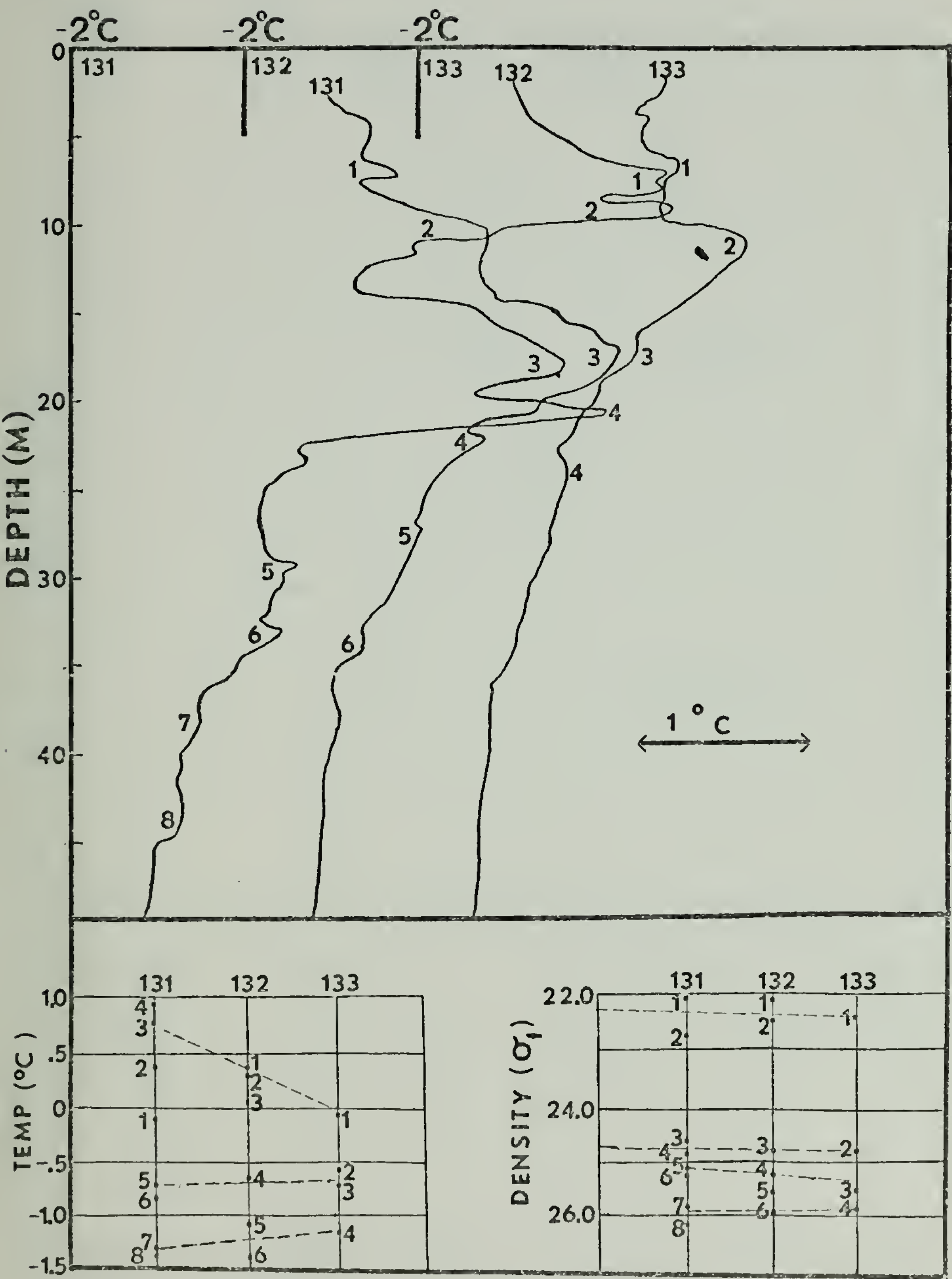


Figure 6. Characteristics of mesostructure elements in stations 131-133.

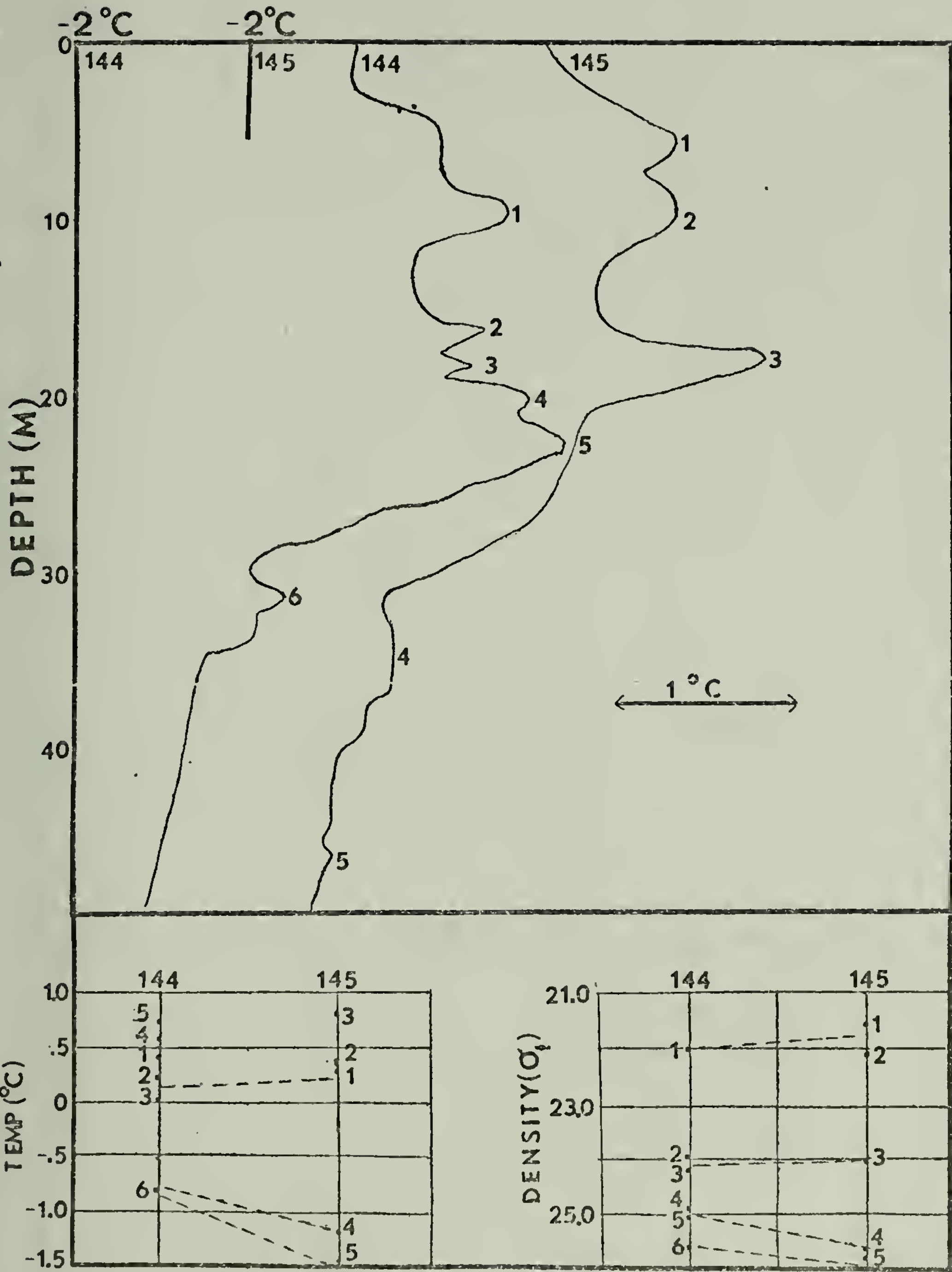


Figure 7. Characteristics of mesostructure elements in stations 144-145.

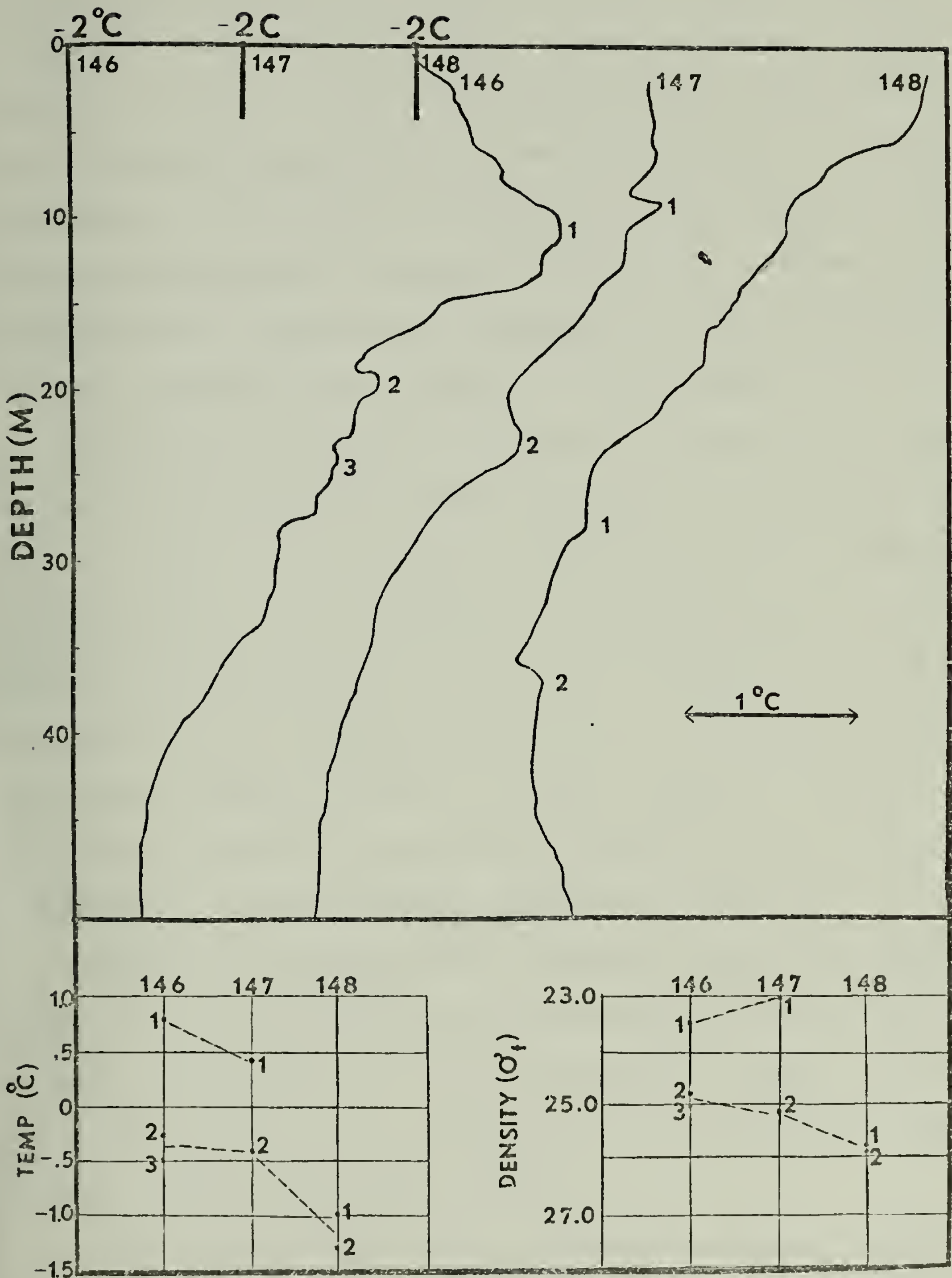


Figure 8. Characteristics of mesostructure elements in stations 146-148.

Stations 144 and 145 (Fig. 7), separated by 1km, showed fairly good correlation between mesostructure elements, although it was more difficult to trace particular elements than in 131-133. However the temperature profiles are similar in shape, suggesting a common origin for the waters. Densities of some of the mesostructure elements at their peaks compared well between the stations. The near-surface mesostructure temperatures changed more than the temperatures of deep mesostructures, which is to be expected.

Again in stations 146-148 (Fig. 8), some of the structures seem to be correlated, especially between stations 146 and 147, but it is difficult to demonstrate the correlation unambiguously between stations 146 or 147 and station 148. Stations 147 and 148 are 1 and 10 km from station 146, respectively. This suggests either that the length scale of particular mesostructures is short compared to 10km or that the line along which progressive change occurs (perhaps a pressure ridge) was sharply defined, or both.

Therefore, mesostructure elements seem to be capable of existing and maintaining their identity for up to 1km, although some elements either disappear or change so as to become unrecognizable in that distance. No definite continuity can be shown over a 10km distance.

Studies were made of the temporal variation of mesostructure elements, using stations 7-16 and 17-35, (see figures 9, 10, and 11). When initially analyzed, it was found that the 25.5 sigma-t surface could change as much as six meters

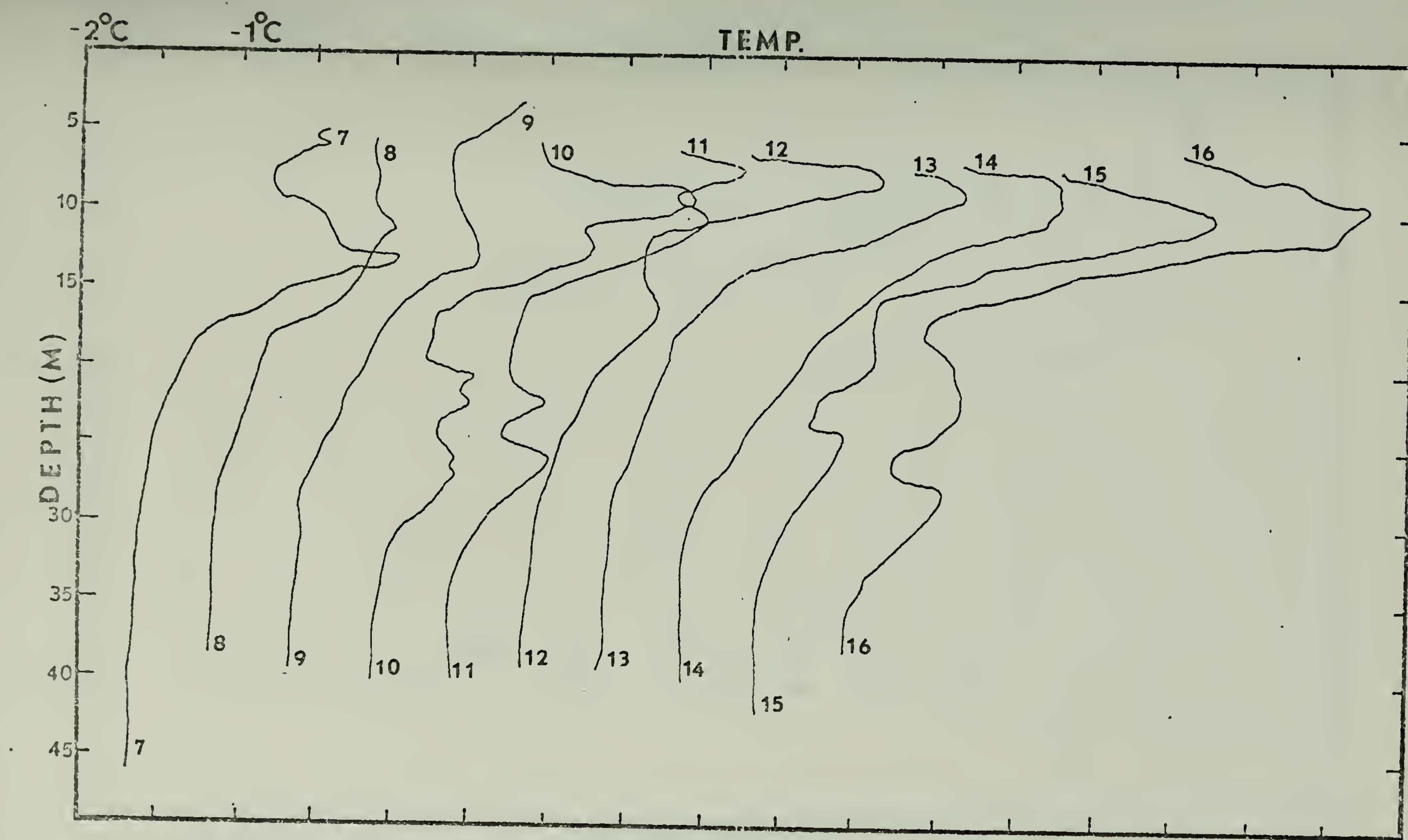


Figure 9. T-Z profiles of stations 7-16 nested with one-degree separations.

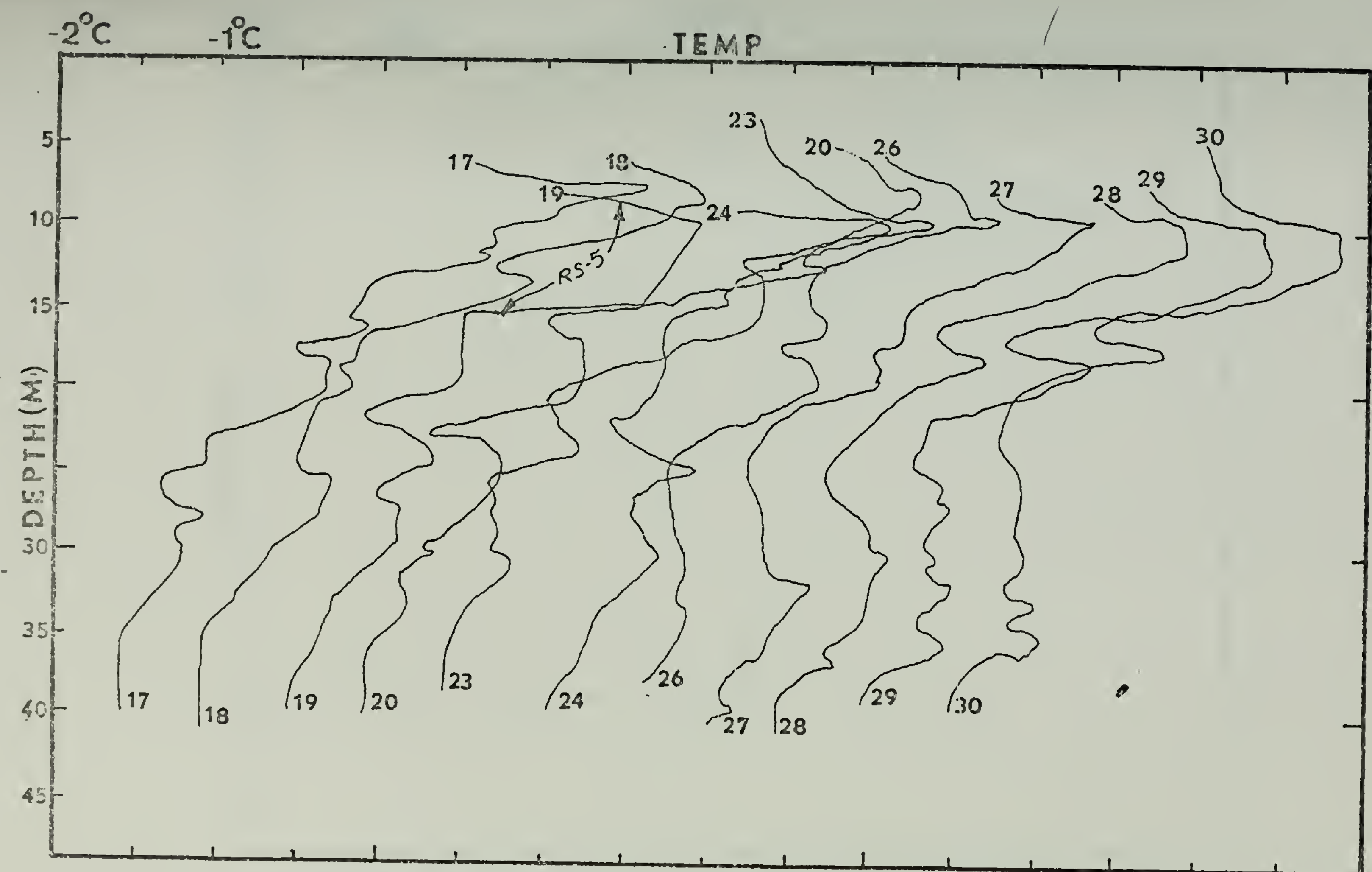


Figure 10. T-Z profiles of stations 17-30 nested with one-degree separations.

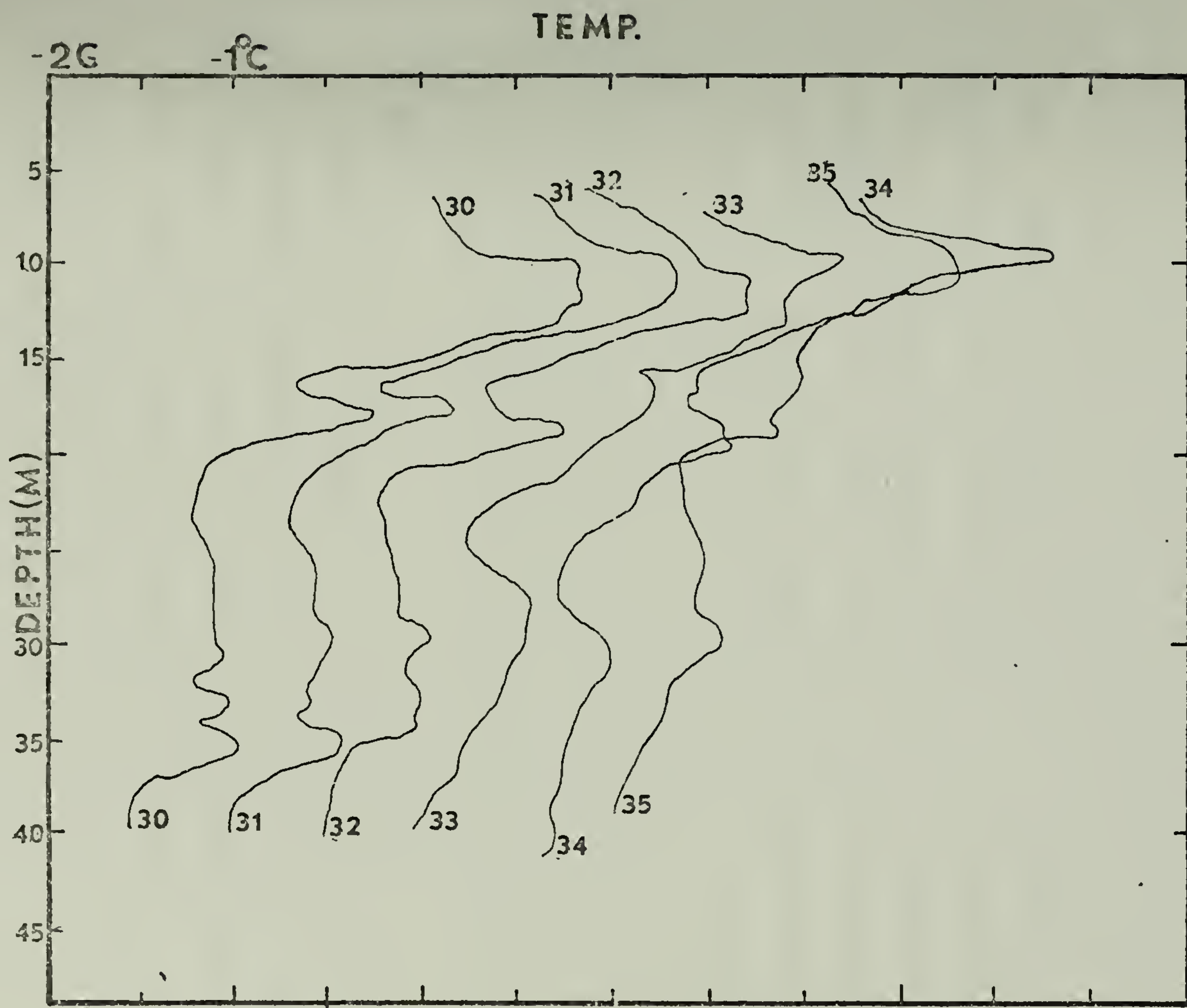


Figure 11. T-Z profiles of stations 30-35 nested with one-degree separations.

in depth in the space of $2\frac{1}{2}$ hours. Therefore, to trace mesostructure, a graph was devised which simultaneously plotted the depth of constant-density surfaces versus time and mesostructure depth versus time. This graph (Fig. 12) has the times of stations 7-16 and 17-35 marked on the abcissa to give a time perspective to mesostructure and density variations. The stations appear to be out of sequence (i.e. between 16 and 7, and 35 and 17), but it was decided to use time as the common denominator in order to observe whether fluctuations of the density surface had a dependence on the time of day. This form of graph has the advantage of allowing one to observe the density variation of mesostructure elements while also seeing what is happening to the water column itself. The thick vertical bars represent the limit in depth and density of the mesostructure elements. Those bars labeled with an "N" are noses as defined in the introduction.

Mesostructure elements in figures 9, 10, and 11 show some temporal continuity. The shallow nose was present in stations 7-35 to varying degrees. The shallow mesostructure element below the nose in stations 28-33 remained similar in temperature, shape, and density for a period of six hours, (see also Fig. 12).

There is some correlation in temperature, shape, and density between deep mesostructure elements from 30-40 meters depth in stations 29-32 as well as between stations 10-11 and 15-16. The deep structure in those cases is mostly in

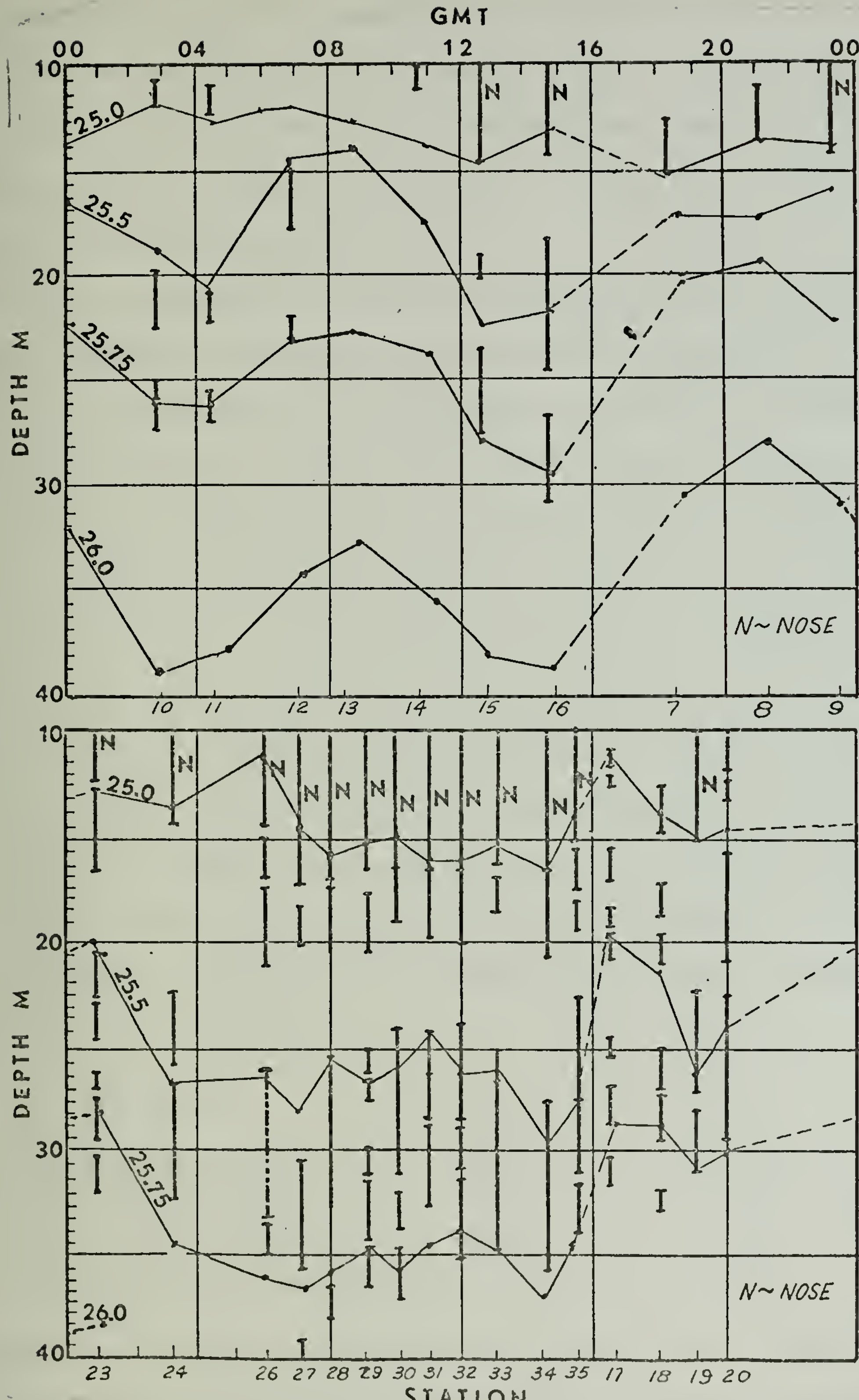


Figure 12. Depth/Density characteristics of stations 7-35. The vertical bars indicate the depth ranges in which mesostructure is present.

the 25.5-25.9 sigma-t range. Most other deep mesostructures in the time series also occurred in this density range. It is interesting to note that the structures seem to divide into two density ranges ($\sigma_t<25$ and $25.5<\sigma_t<25.9$) in the time series, as was noted earlier.

Since the temporal variation in the depth of constant-density surfaces appeared to be cyclical, especially in stations 7-16, periods of oscillation were measured approximately to the nearest hour. Stations 7-16 appeared to have a period of 12 hours, while stations 17-35 had a poorly defined peak with a period of perhaps 14 hours. A 24 hour period may exist but cannot be demonstrated in so short a series. The presence of tidally generated internal waves must be suspected. It is commonly known that intensification of wave energy often occurs along continental slopes, and there is no reason to suspect that the case is any different here. Additional support is given for this idea when the time (GMT) of occurrence of peaks and troughs of the density surfaces in Fig. 12 is examined:

STATIONS	7-16	17-35
GMT OF LARGE PEAK	2100	1700-0200
GMT OF SMALL PEAK	0900	1200
GMT OF FIRST TROUGH	0300	0700
GMT OF SECOND TROUGH	1300-1500	1500

Because water of an inhomogeneous nature is being advected, and because stations were an hour apart or more, the hour of maximum or minimum could easily be displaced ±1 hour from the values shown.

Another feature of Figure 12 is worth mentioning. Stations 7-16 contain the 26.0 sigma-t surface at a depth of between 28 and 39 meters. This surface is at its maximum depth when deep mesostructure is occurring. Stations 17-35 have continuous deep mesostructure. The 26.0 sigma-t surface is found between 38 and 40 meters for stations 17 through 23, and then not at all for remaining stations.

B. CHARACTERISTICS OF STATIONS 131-163

To determine if mesostructure densities and depths throughout the MIZPAC 71 area were similar to those in Stations 7-35, T-S and T-Z profiles were examined. Figures 13, 14, and 15 show depths of mesostructure elements for Stations 131-163. Again, time is on the abcissa. The three figures are for stations taken on August 18, 19, and 20, respectively. It is important to note that these graphs involve variations in both time and space whereas in Figure 12 the variation in time is predominant. But in order to see if long-period internal waves could be observed, and in the interest of pointing out the similarities that do exist with Figure 12, the stations have been plotted in a time/depth coordinate system. Again depths of constant sigma-t surfaces and depths of mesostructure elements and noses have been plotted.

There is some agreement between Figures 13, 14, 15, and Figure 12 regarding tidally generated oscillations. The GMT of the peaks and troughs of constant-density surfaces

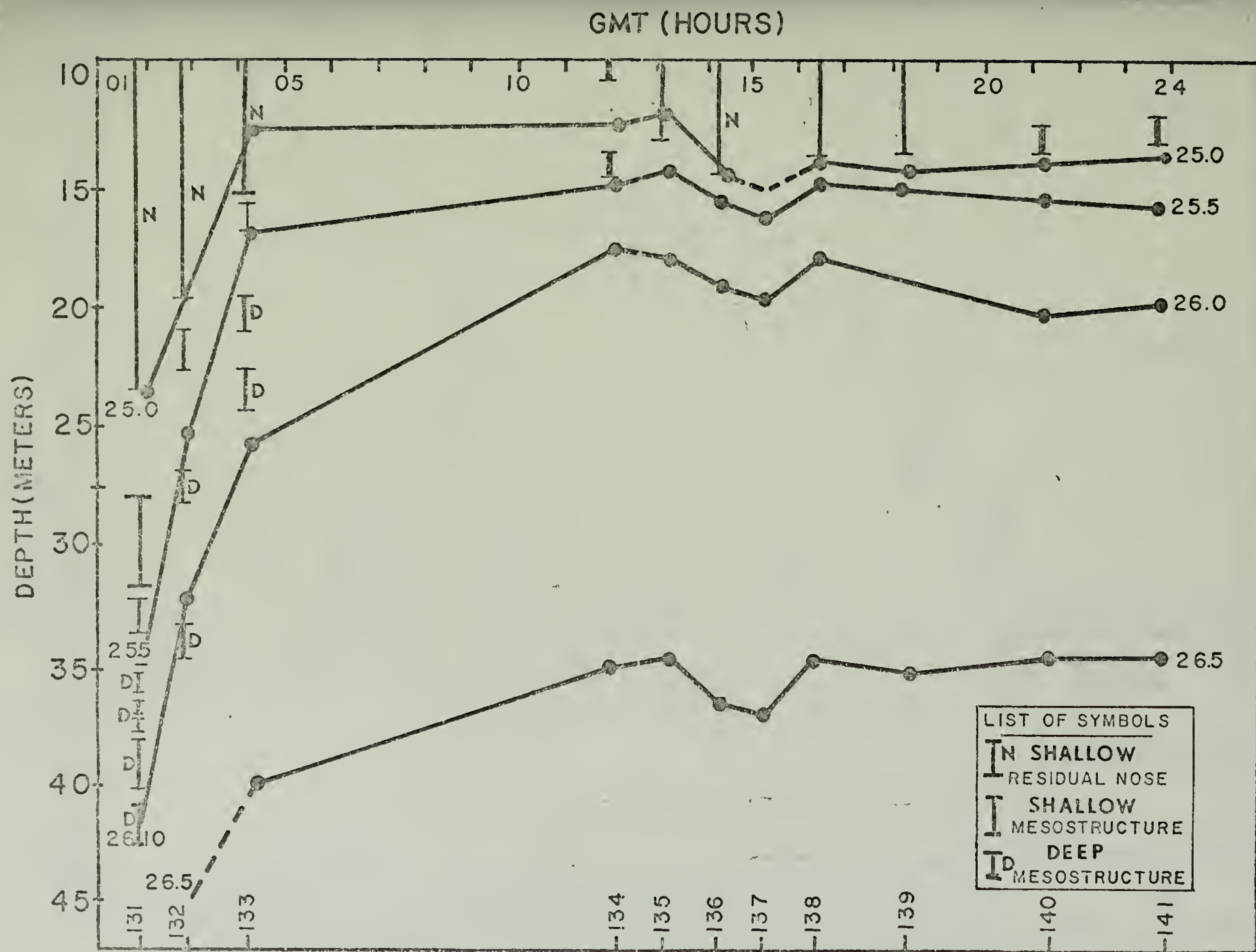


Figure 13. Depth/Density characteristics of stations 131-141 (18 August).

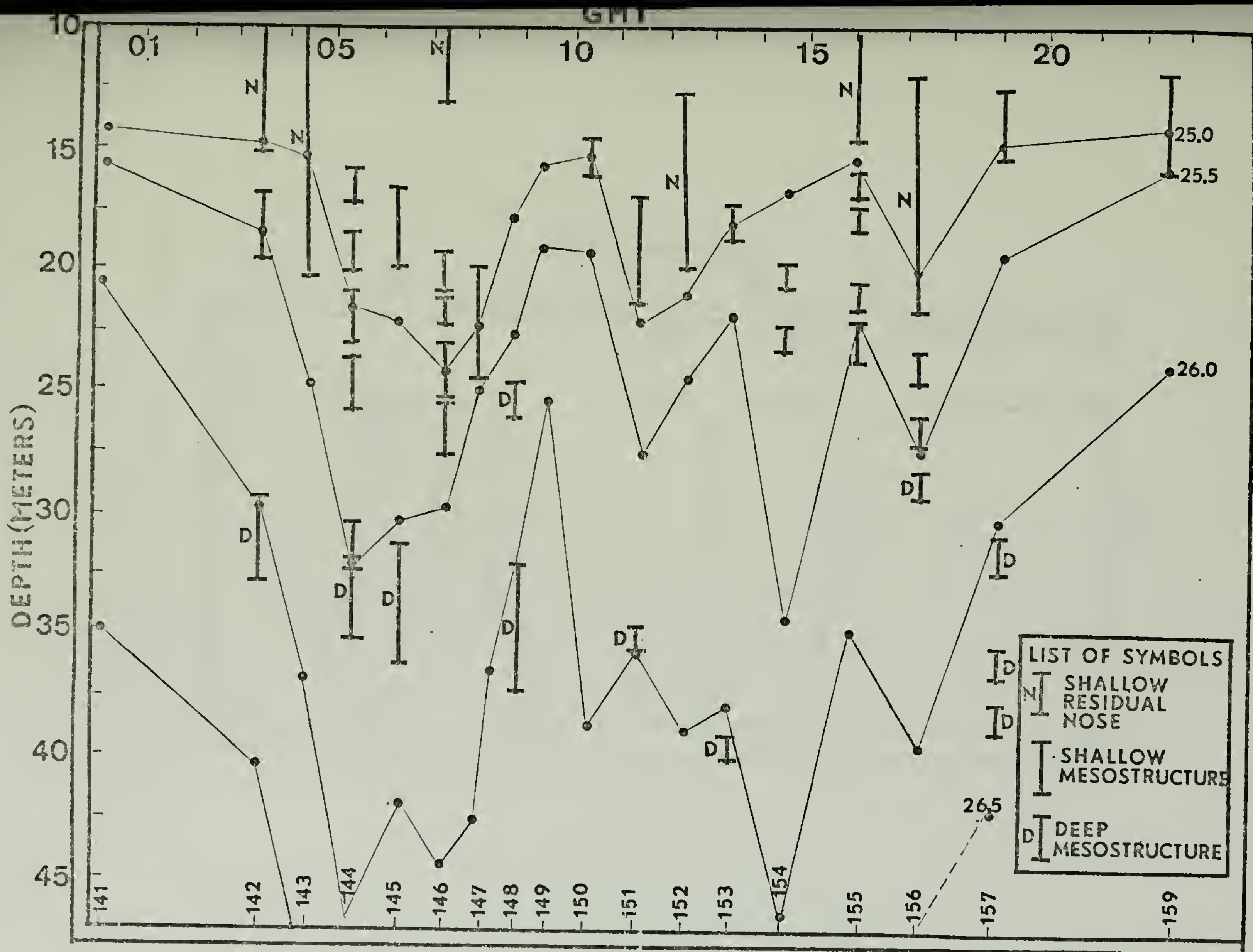


Figure 14. Depth/Density characteristics of stations 142-159 (19 August).

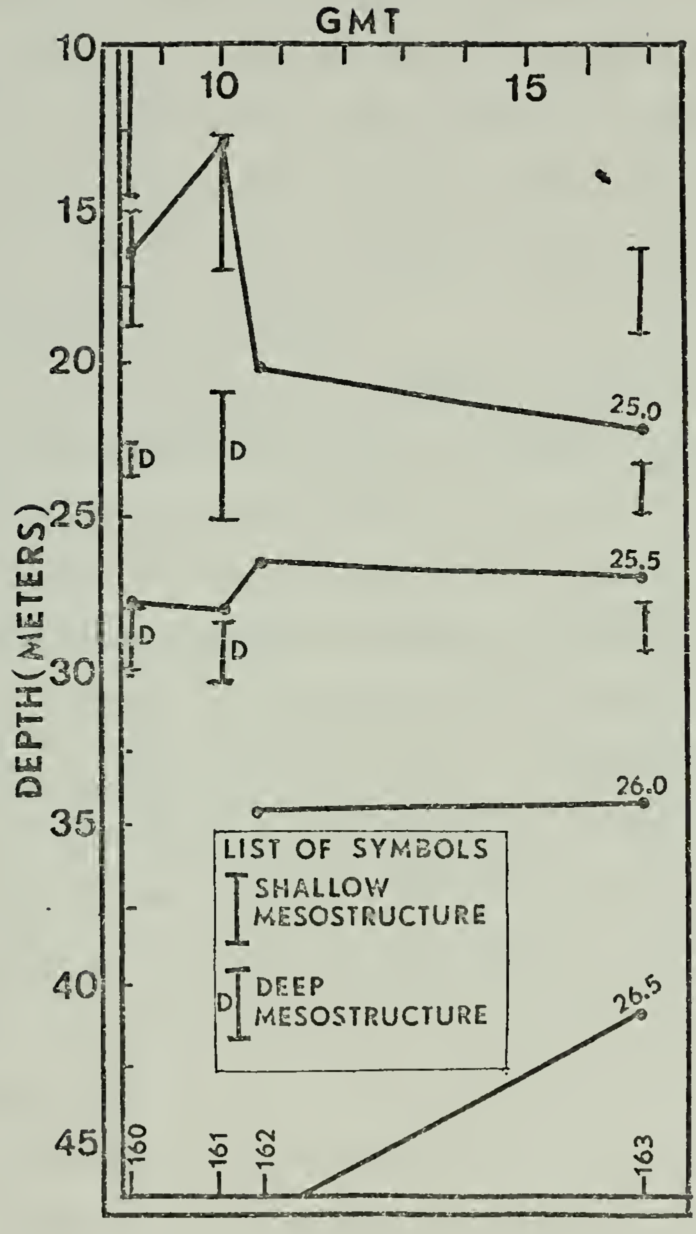
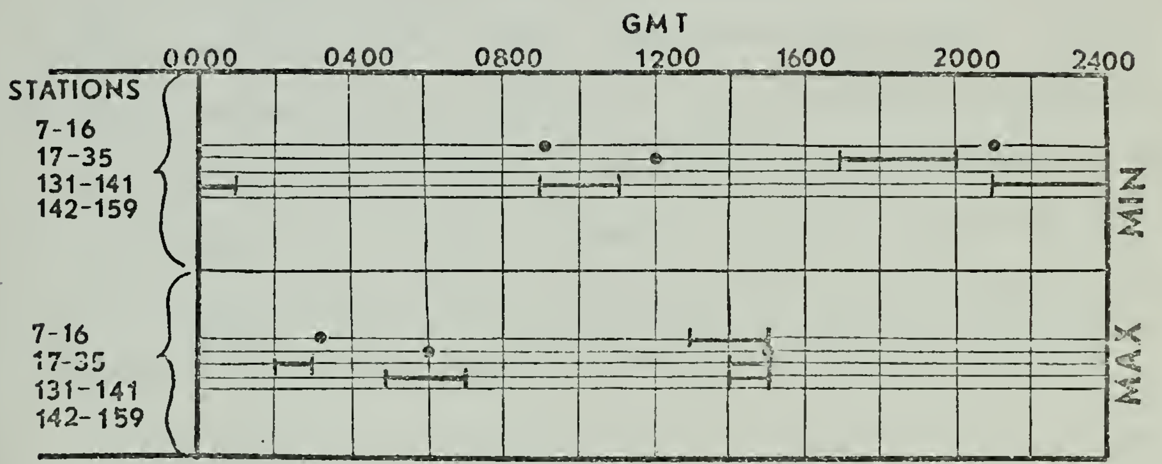


Figure 15. Depth/Density characteristics of stations 160-163 (20 August).

correspond fairly well to times found for stations 7-16 and 17-35. On August 18 definite troughs were found at 0200-0300 GMT and 1400-1500 GMT, roughly a 12 hour interval. Because there were few stations between 0400 and 1200 GMT, it is not known where a peak would have occurred. It is interesting to note that the temporal change in depth of the density surface is small for Stations 138-141. These stations are the farthest out on the Chukchi shelf of any stations studied using MIZPAC 71 data.

Peaks in the density surfaces on August 19 were found at 2100-0100 GMT and 0900-1100 GMT. Troughs were located at 0500-0700 GMT and 1400-1500 GMT. No data were used from August 20 since only four stations were occupied. The times of all peaks and troughs are shown in Figure 16. Points were used in place of lines when the times of peaks seemed to be close to the station times. The ranges shown only consist of the time spread of the actual estimates made, without the ±1 hour of uncertainty. Judging from this figure it seems probable that there is significant internal wave activity in the area over and to the southwest of the Barrow Sea Valley along the border of the Chukchi Sea coastal shelf. It is curious that the peaks are so well correlated in time, when the size of the area would suggest that there should be substantial phase differences between stations. This suggests that a wave phenomenon exists which has roughly a 12 hour period and a very long wavelength. This could conceivably be driven by internal edge waves in the Arctic Ocean.



ESTIMATED TIMES OF OCCURRENCE OF DENSITY MINIMUMS AND MAXIMUMS FOR MIZPAC 71 STATIONS 7-35 AND 131-159

Figure 16.

It should be noted that this oscillatory activity is not confined to the near-surface as is evident by following the 26.0 sigma-t surface on August 18, 19, and 20, as well as the 25.75 sigma-t surface for stations 7-35.

In stations 131-163 (see Figs. 13, 14, and 15) a warm nose was found everywhere except when near-surface densities were high. Shallow mesostructure was also found in most stations. Deep mesostructure occurred only when the 25.5 σ_t density surfaces were deeper than about 25 meters. However, as will be shown, the association of deep mesostructure is not so much with low density as with high temperature. Most of the deep mesostructure elements occurred in the 25.5-25.9 sigma-t range. This density range is the same as for the majority of the deep mesostructure in stations 7-35.

C. COMPARISON OF STATIONS IN THE ICE MARGIN WITH AND WITHOUT MESOSTRUCTURE

Thus far it has been found that mesostructure occurrence is associated with relative maximums of the depth of density surfaces. Much of the deep mesostructure has been found in the 25.5-25.9 sigma-t range. It was found that the occurrence of mesostructure in this density range was associated with the appearance of a warm shallow nose of lesser density, and generally some shallow mesostructure.

In order to see if the nose was more closely related to deep mesostructure, and thus predictive of its existence, maximum temperatures (which were always in the shallow nose)

of stations with deep mesostructures and stations without deep mesostructure were compared (Fig. 17). This figure includes temperature data from stations in the time series and the stations 131-163. Stations with mesostructure elements in the density range 25.5-25.9 sigma-t, greater than 26.0 sigma-t, and those without deep mesostructure elements ($25.5 \leq \sigma_t < 25.9$) were compared. The average near-surface temperature of stations with 25.5-25.9 sigma-t was found to be 1°C. Stations with mesostructure at sigma-t $\geq$ 26.0 had the same mean maximum temperature. However, stations without much mesostructure below the near-surface nose had an average temperature about -1.3°C, 2.3°C cooler. Therefore, when deep mesostructure is occurring, it is likely that near-surface waters have temperatures above the ice-seawater equilibrium temperature.

D. ORIGIN OF MESOSTRUCTURE ELEMENTS

At this point mesostructure has been associated with relatively warm near-surface temperatures as well as with the periodic descent of constant density surfaces. The phenomenon was determined to be patchy, with stations only several km apart showing much different temperature-depth profiles. The length scale of particular mesostructure elements was concluded to be at least 1km, with possible continuity up to 10km. Mesostructure was not seen to persist at one area for more than a day. Tracing of mesostructure indicated that the process was a dynamic one, with notable changes in the structure occurring in the space of a few km.

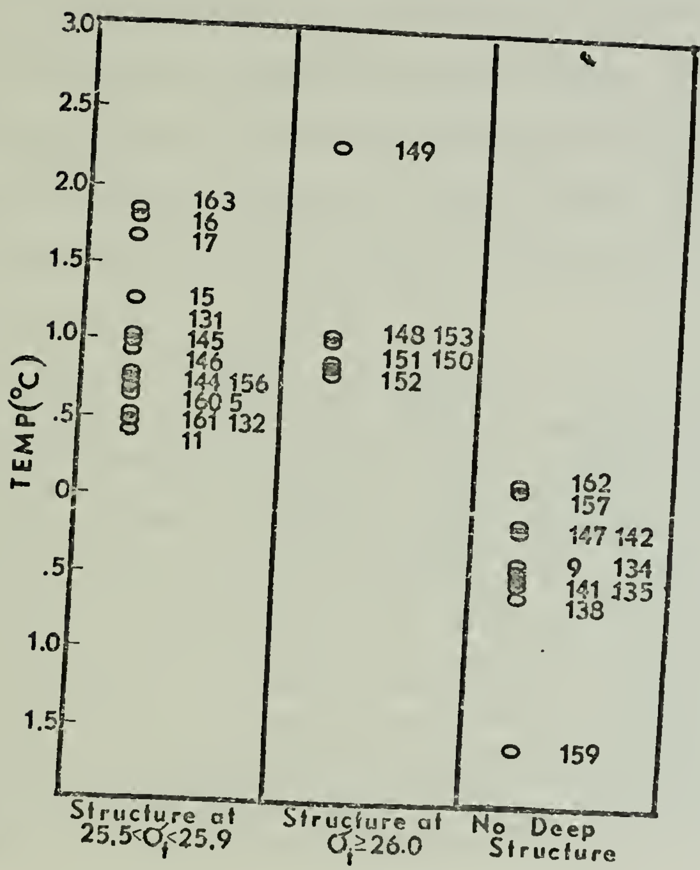


Figure 17. Maximum temperatures for some MIZPAC 72 stations inside the ice margin.

Mesostructure appeared to exhibit a tendency to split into shallow and deep structure at times, as was especially indicated by the time series 7-35. Mesostructure was found to apparently occur only inside the ice margin.

To find a suitable explanation for all of these results, the origin of mesostructure elements was investigated using theories of breaking internal waves by shear instability or convective overturning, local vertical mixing, salt fingering, billow turbulence, and advection. Most of these theories were discarded either because of lack of agreement with observations, or lack of data:

* The breaking of internal waves by shear instability can account for formation of warm mixed water near the base of the warm nose. However breaking internal waves cannot move the water directly vertically downward without also mixing the water column. As will be discussed, this mixed water may provide the source water for creation of mesostructure by advection into adjacent water columns.

* The breaking of internal waves by convective overturning (Orlanski and Bryan, 1969) again cannot account for direct vertical transfer of heat, and suggests a mechanism for forming a staircase type of structure rather than the large-scale positive temperature anomalies observed.

* Local vertical mixing by turbulent eddies can cause vertical heat transfer, but the mixing process tends to produce smooth temperature gradients.

* Salt fingering can cause a structural element to change depth and temperature, but it cannot account for the initial formation of elements like the ones observed.

* Billow turbulence (Woods and Wiley, 1971) can account for splitting of an element into smaller structure, but is concerned with such small scale phenomena that its applicability is limited to a possible explanation for degeneration of structure.

Since no suitable explanation could be found in the literature, advection was considered. A source of warm water was required in the density range at which mesostructure elements were observed. Stations 40-48, in the coastal current, were found to contain a significant proportion of their heat in the density range of up to almost 26.0 sigma-t. This heat was found to be generally confined to the upper 15 meters or so of the water column, overlying much colder water. Figure 18 shows the general characteristics of the stations in the area of 40-48, outside the marginal ice zone and in the coastal current.

The author's picture of the process which apparently is occurring in the marginal ice zone of the northeastern Chukchi Sea, is summarized in Figure 19. This figure shows the progression of water from outside the ice margin to anywhere from 1 to 20km inside. The sloping of the isopycnals as drawn was actually observed. It is not known whether this is due more to a geostrophic tilting of the isopycnals in response to the coastal current or a result of ice melting.

As the figure shows, warm water (from the coastal current) enters the ice margin, where the surface is quickly cooled and diluted by ice melting. The temperature profile is modified from a sharply-defined staircase structure to a sub-surface nose feature. Under-ice turbulence generated by flow past ice protuberances causes mixing at both the top and bottom of the nose. This mixing increases the density of the bottom of the warm nose, and provides water of the

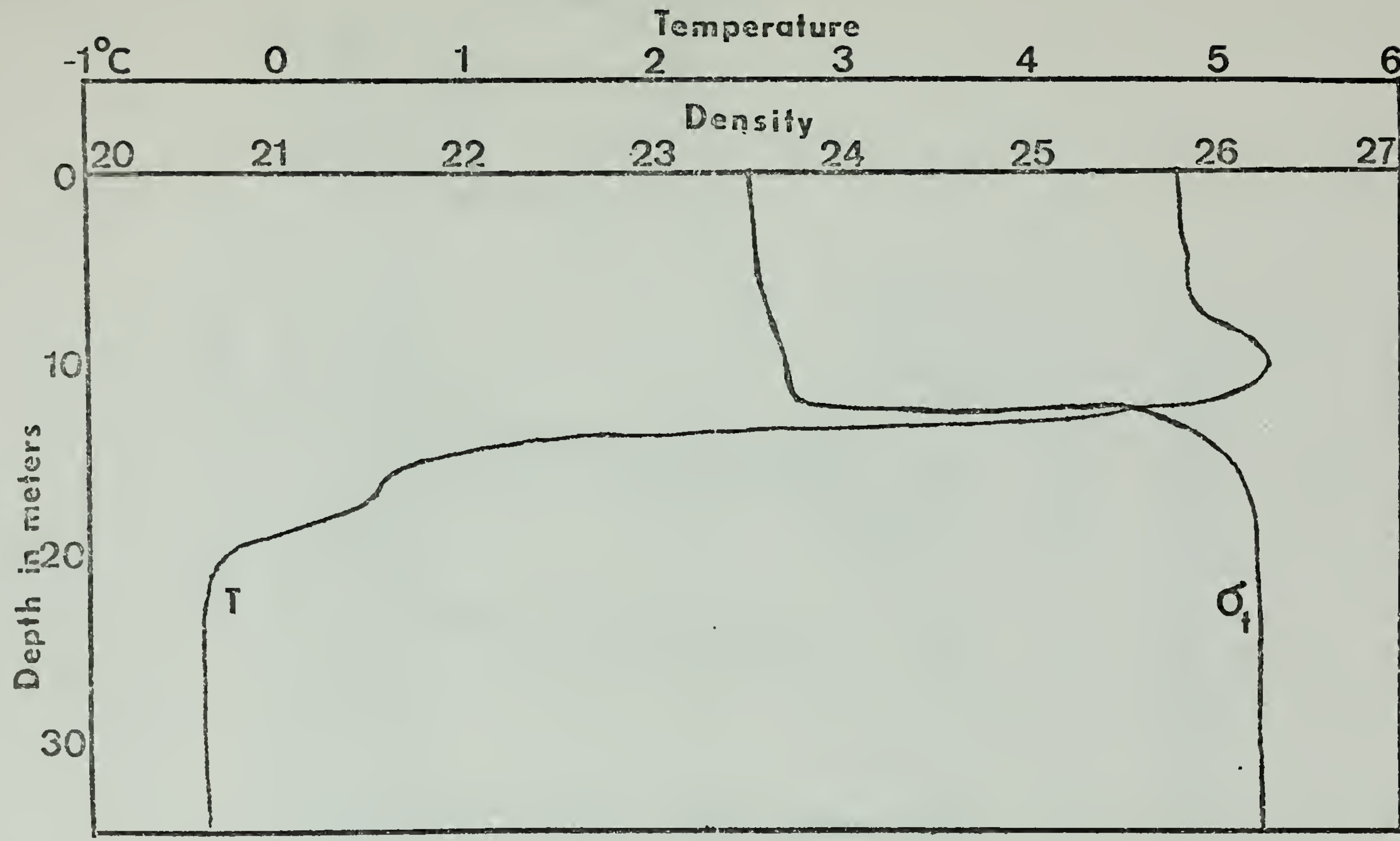


Figure 18. Typical characteristics of MIZPAC 71 stations south of the ice margin inside the coastal current

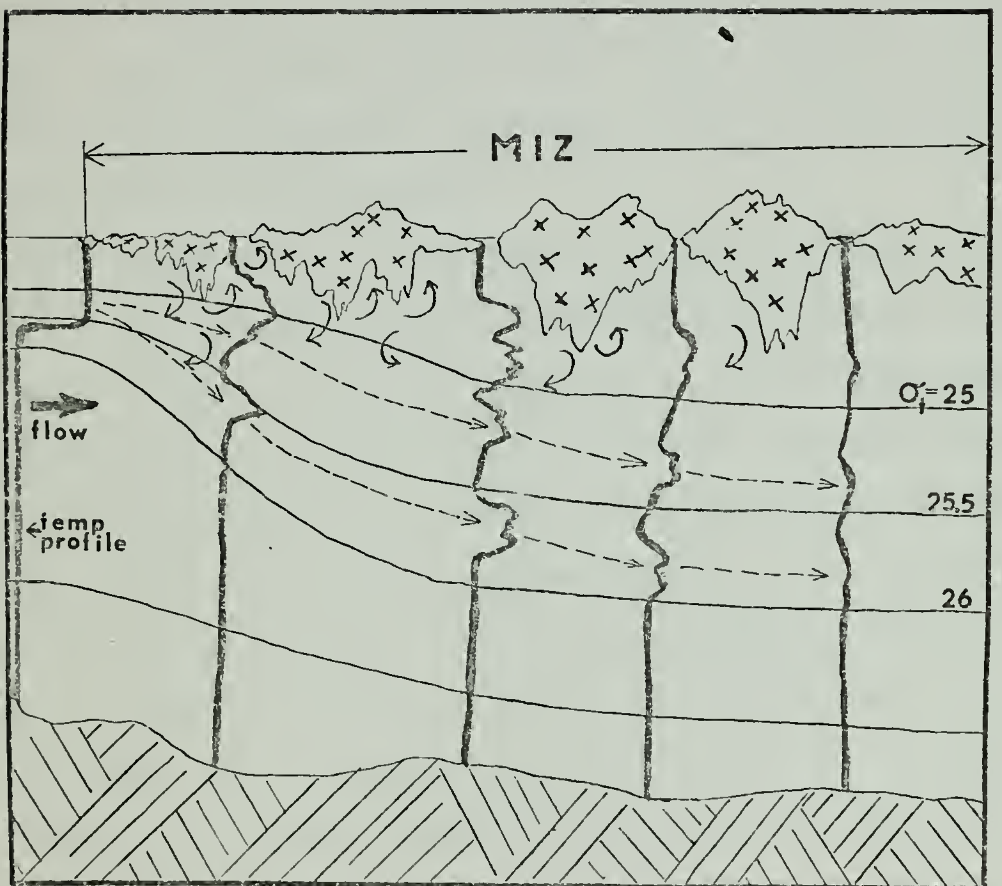


Figure 19. Mesostructure formation and decay within the marginal ice zone.

necessary temperature and density to serve as source water for the creation of positive temperature anomalies in adjacent water column with different density structures. This water intrudes into adjacent water columns in a more or less horizontal direction as an interleaving feature forming mesostructure elements. The intrusion appears to be somewhat random, but is highly likely, since water columns only 1km inside the ice margin have generally lower densities than those outside the ice margin.

Since some heat is already available in the density range in which the great majority of the mesostructure was found, the warm coastal water does not have to be modified much, and merely seeks its density in the water inside the MIZ. The fact that warm water inside the ice margin is found 25 meters deeper than in the coastal current is not inconsistent with this theory (recall that the 26.0 sigma-t surface was found at depths of up to 40 meters inside the ice margin and at 15 meters in the coastal current). Finally, depending on the amount of current shear and turbulence in the area, both the nose and the mesostructure decay as their heat is lost. Because of the highly dynamic conditions in the marginal ice zone, mesostructure elements may decay in anywhere from perhaps 1km to 20km or more. The pycnocline may act as an energy hill, keeping most of the heat from the coastal current in the upper 15 meters. Once structure has either found its way below this pycnocline, or initially interleaved below it, it is virtually free to move in the water column, since the

change in density with depth is very slight. It is interesting to note that most of the deep structure does occur when density surfaces are at a maximum depth, possibly indicating that the density barrier has been decreased. It is also logical to expect more of the warm dense water initially mixed below the pycnocline to be found at depths of up to 40 meters when density surfaces are at their greatest depths.

The banding observed at some stations may be related to the periodic descent of sigma-t surfaces. Figures 20 and 21 give some support for this idea. In stations 17-20 the mesostructure elements have little uniformity in density or depth (see also Figures 10 and 12). At this point density surfaces are at a relative minimum depth. Stations 33-35 in Figure 21 show banding, and were occupied when the density surfaces were at a relative maximum in depth.

Near-surface temperatures appear to be related to the depth of sigma-t surfaces since temps were found to be higher in stations with deep mesostructure than in stations without deep structure. Further conclusions require additional supporting data.

The author feels that the theory of interleaving is plausible and consistent with the data. It was not possible with the data available to trace the interleaving process in detail. Further work should include closely spaced stations to make this possible. Some interesting associations between mesostructure and internal waves have been suggested, however time prevented this phenomenon from being studied more thoroughly.

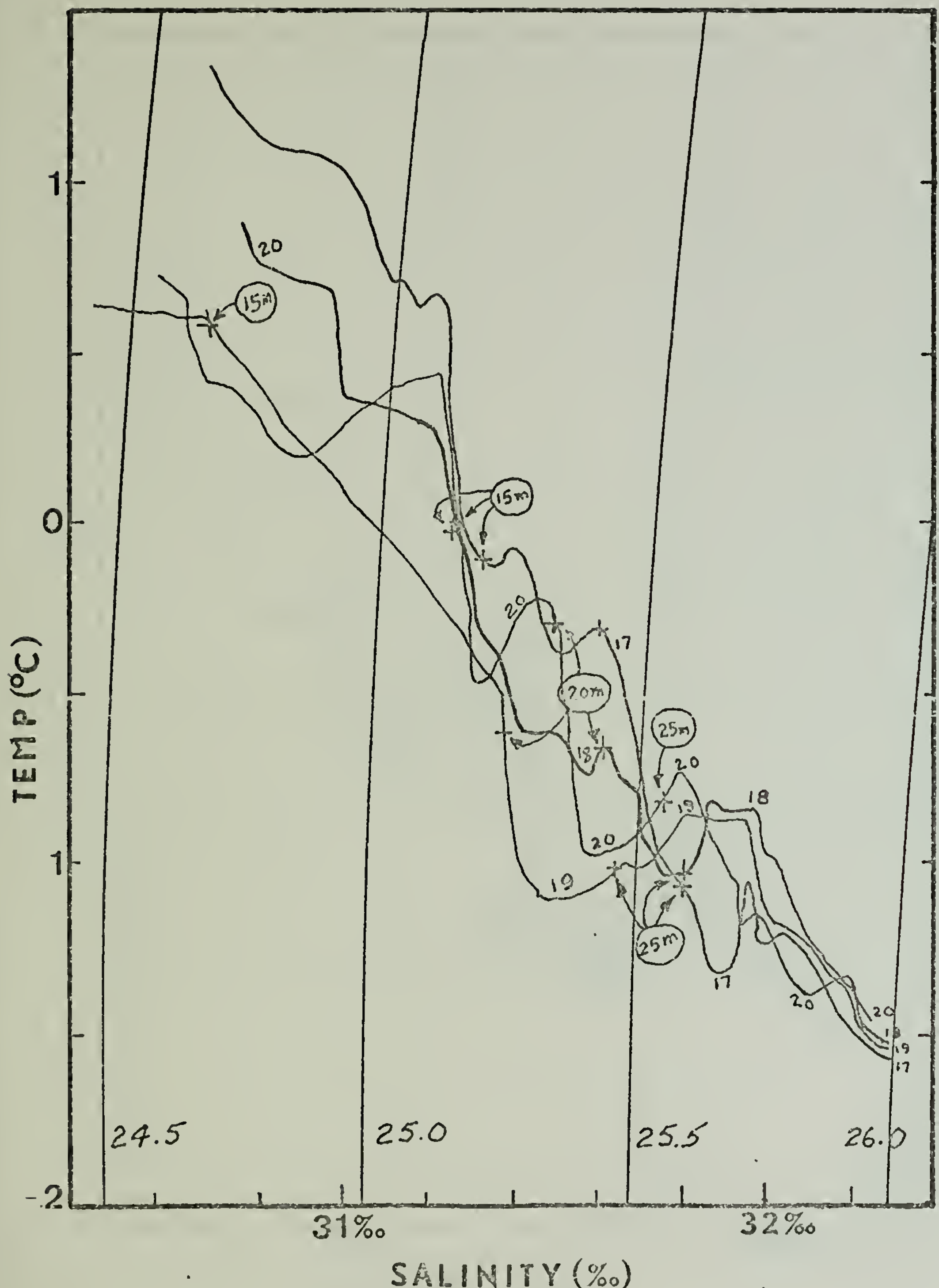


Figure 20. T-S grouping of stations 17,18,19,20.

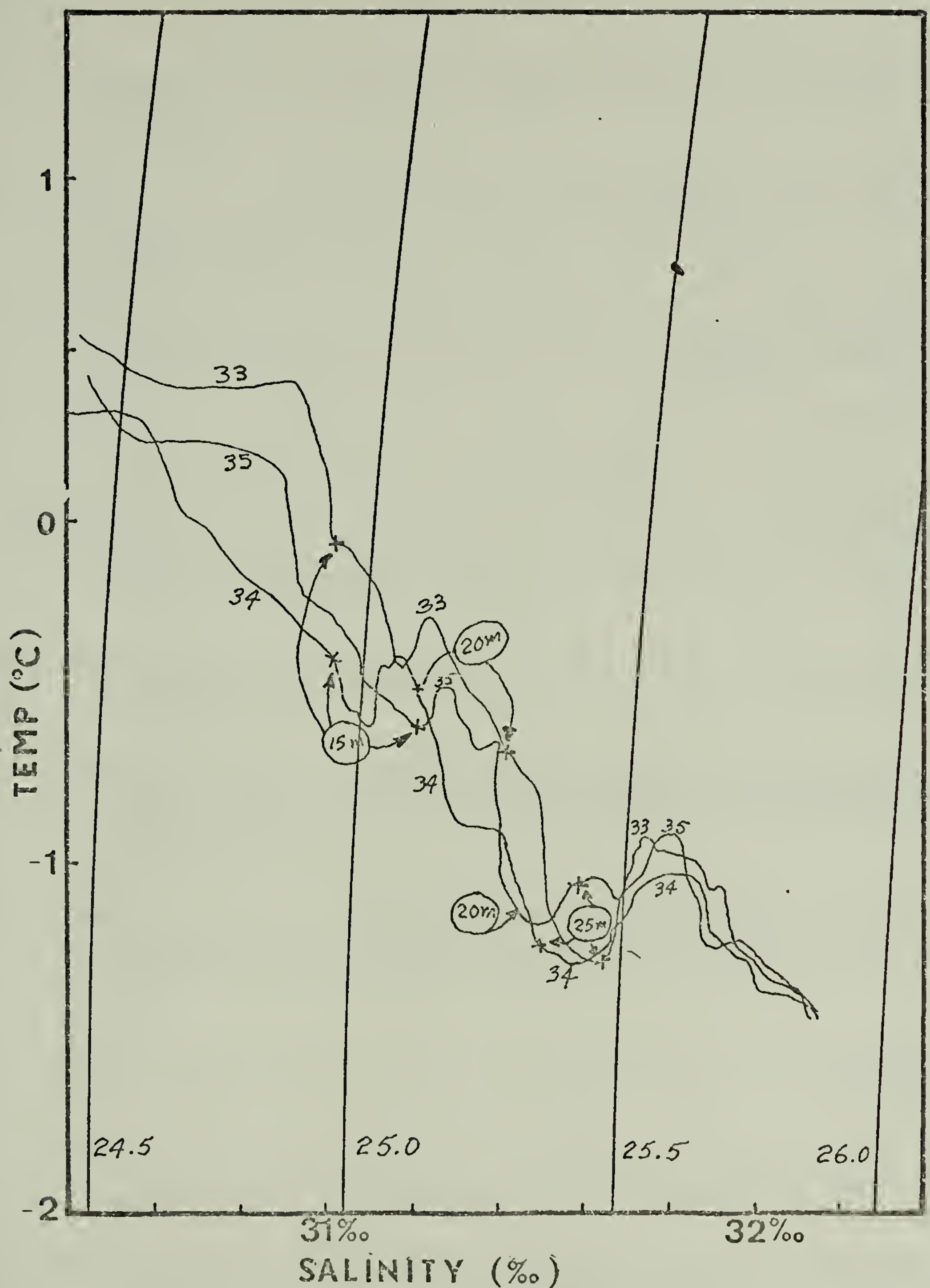


Figure 21. T-S grouping of stations 33,34,35.

BIBLIOGRAPHY

1. Coachman, L.K. and C.A. Barnes (1961). "The contribution of Bering Sea Water to the Arctic Ocean." Arctic 14: 147-161.

2. Denner, W.R. (1971). "The layered microstructure and acoustic propagation in the Arctic Ocean." J. Underwater Acoust., Vol. 21, No. 1, pp. 45-51.

3. Frankignoul, C.J. (1972). "Stability of finite amplitude internal waves in a shear flow." Geophys. Fluid Dyn., London, Gordon Breach Science Publishers Ltd, 4:91-99.

4. Garrett, C. and W. Munk (1972). "Oceanic mixing by breaking internal waves." Deep-Sea Res., 19:828-832.

5. Garrison, G.R., E. Pence, H. Feldman, S. Shah (1974). Studies in the marginal ice zone of the Chukchi Sea. Univ. of Washington, Applied Physics Lab., Rept. #APL-UW 7311, 127 p.

6. Gregg, M.C. and G.S. Cox (1972). "The vertical microstructure of temperature and salinity." Deep-Sea Res., 19:355-376.

7. Hufford, G.L., Dissolved oxygen and nutrients along the North Alaskan Shelf, Paper presented at Symposium on Beaufort Sea Coastal and Shelf Research, San Francisco, January 1974.

8. Mountain, D.G., Beaufort shelf circulation: preliminary analysis, Paper presented at Symposium on Beaufort Sea Coastal and Shelf Research, San Francisco, January 1974.

9. Neal, V.N. et al. (1972). "Microstructure anomalies in the Arctic Ocean." J. Geophys. Res., 78(15):2695-2701.

10. Orlanski, I. and K. Gryan (1969). "Formation of thermocline step structure by large-amplitude internal gravity waves." J. Geophys. Res., 74(28):6975-6983.

11. Paquette, R.G. and R.H. Bourke (1973). Oceanographic measurements near the arctic ice margins. Naval Postgraduate School, Monterey, Tech. Rept. NPS-58PA73121A, 96 p.

12. Paquette, R.G. and R.H. Bourke (1974). "Observations of the coastal current of Northwestern Alaska." J. Mar. Res., 32(2):195-207.

13. Woods, J.D. and R.L. Wiley (1972). "Billow turbulence and ocean microstructure." Deep-Sea Res., 19:87-21.

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Department of Oceanography, Code 58 Naval Postgraduate School Monterey, California 93940	3
2.	Oceanographer of the Navy Hoffman Building No. 2 200 Stovall Street Alexandria, Virginia 22332	1
3.	Office of Naval Research Code 480 Arlington, Virginia 22217	1
4.	Dr. Robert E. Stevenson Scientific Liaison Office, ONR Scripps Institution of Oceanography La Jolla, California 92037	1
5.	Library, Code 3330 Naval Oceanographic Office Washington, D.C. 20373	1
6.	SIO Library University of California, San Diego P.O. Box 2367 La Jolla, California 92037	1
7.	Department of Oceanography Library University of Washington Seattle, Washington 98105	1
8.	Department of Oceanography Library Oregon State University Corvallis, Oregon 97331	1
9.	Commanding Officer Fleet Numerical Weather Central Monterey, California 93940	1
10.	Commanding Officer Environmental Prediction Research Facility Monterey, California 93940	1
11.	Department of the Navy Commander Oceanographic System Pacific Box 1390 FPO San Francisco 96610	1

12.	Defense Documentation Center Cameron Station Alexandria, Virginia 22314	2
13.	Library (Code 0212) Naval Postgraduate School Monterey, California 93940	2
14.	Assoc. Prof. Robert G. Paquette, Code 58Pa Department of Oceanography Naval Postgraduate School Monterey, California 93940	4
15.	Asst. Prof. Robert H. Bourke, Code 58Bf Department of Oceanography Naval Postgraduate School Monterey, California 93940	1
16.	Director, Arctic Submarine Laboratory Code 90, Building 371 Naval Undersea Center San Diego, California 92132	1
17.	ENS William R. Corse, USN 1848 Longview Drive Lancaster, Pennsylvania 17601	3

Thesis 156142
C7556 Corse
c.1 An oceanographic investigation of mesostructure near Arctic ice margins.